Reconstructing the Minoan Communication Network in Central Crete

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Abstract

The Pediada survey is an interdisciplinary project, based on fieldwork carried out between 1982 and 1989 by the archaeologist Dr. Niko Panagiotaki. The systematic survey campaign which covered a total area of 800 sq. km. in the Pediada region in central Crete (area near modern Herakleion) brought to light a registry of more than 2500 sites of archaeological interest spanning from the Neolithic to the end of the 19th century A.D. One of the most distinct features that were recognized along the surface survey was S*oroi*, a series of man made rounded pyramidal structures with a flat top, showing evidence of burned residues.

In order to test the theory suggested by Dr. Panagiotakis, namely that the above features constitute fire signaling beacons used for communication among Minoan sites, a number of spatial and statistical techniques were employed. Landsat, SPOT and ASTER images were used to investigate the spectral signature of the particular features. The environmental and spatial attributes of *Soroi* were cross-correlated with the rest of the archaeological sites. Clustering and spatial cohesion of them was explored, compared to the rest of the settlements. Proximity distance to settlements of the same period indicated a close relation between settlements and *Soroi*. The inter-visibility among *Soroi* and the control of communication passages was tested through viewshed analyses. The particular results suggest a probable hierarchy of *Soroi* depending on their location and size – the most significant of them being located at the west and east borders of the Pediada region, controlling in this way the passages/routes from the east and west mountain ranges. Supervised classification techniques were also applied to the satellite imagery in an effort to locate probable locations of similar features.

The above approaches support the hypothesis that *Soroi* may constitute the earliest communication system in the Aegean world, playing a vital role in the Minoan landscape, especially during the MMI-MMIIIA periods.

Keywords

Minoan Crete, GIS, Communication, Satellite Remote Sensing, Predictive Modelling

1. Introduction

Between 1982 and 1989 the archaeologist Nikos Panagiotakis conducted an archaeological survey of the Pediada region, located in central Crete. The survey area, about 800 sq. km. in size, covers mainly the plain called Omphalion Pedion (south of modern Herakleion) and the areas north, south and west of it. The aim of the project was to understand and reconstruct human activity in the Pediada region from the Neolithic Period to the present and to clarify the relationship between people and their environment. As a result of this campaign more than 2,500 new archaeological sites of all periods have been located, something that suggests a continuous settlement of the area from the Neolithic to the present (Panagiotakis 2003, 2004).

An electronic inventory system was constructed for the organization of the survey data and for archiving the archaeological information. The ultimate goal of the inventory system was to analyze the data and provide an input for the final GIS system of the project which is going to be used for the spatial processing of the sites and the study of the settlement patterns of the region.

The database of the sites was based on the local toponyms of the area, the nearby village and the chronological period and type of monuments. Toponyms were attributed within the area of villages and rural districts and they were collected through the course of the fieldwork and interaction with the locals. Thus, the approximate spatial limits of the toponyms within each rural district were mapped. Their importance needs to be stressed as they usually seem to be related to the monuments existing in a particular location and contributed to the discovery of the sites themselves. The construction of the relational database was based on the directives and the experience of the Digital Crete's Archaeological Atlas project (Sarris *et al.* 2006a; *forthcoming* 2008).

Apart from the archaeological content of the sites, the database included fields related to the environmental attributes of the sites. Thus, a number of tables were constructed that include information regarding site typology and chronological periods, site dimensions, main structural remains, other movable artifacts, surface visibility, soil type coding, rock types, map references, etc. More descriptive information, photographic material, bibliographic and reference comments were also entered.

Among the most important finds of the Pediada Survey project was a number of man-made structures in the shape of a rounded pyramid with a flat top (*Fig. 1*). As the diagnostic material indicates, the particular sites, named *Soroi* by the local people, belong to the Minoan period. In all *Soroi* there are traces of burning and Panagiotakis has suggested that they were probably used as beacons for fire signalling among settlements. If this hypothesis is true, then *Soroi* constitute the evidence for the earliest communication system in the Aegean world.

Although the physiographic attributes of the soroi in terms of elevation, slope and aspect are not statistically different from those of the rest of Minoan settlements, *Soroi* are quite distinct from the rest of the settlements in terms of their local settings and the human intervention that has been carried out at the specific locations.

2. Visualization of archaeological sites in the Pediada region

For better mapping and spatial analysis of the Pediada survey data, a number of cartographic materials were retrieved and digitized. The archaeological sites have been surveyed with a hand-held Garmin 12XL GPS unit having an accuracy of less than 10m. Topographic maps of the Geographic Service of the Hellenic Army (scale 1:50.000) were used for digitizing villages, the main as well as the secondary road network. The geological data were retrieved from a generalization of the geological maps of the Institute of Geological and Mineralogical Studies (IGME), which was one of the products of the EMERIC I project (Sarris 2007; Sarris *et al.* 2006b).

Four geo-rectified Landsat-5 TM and Landsat-7 ETM satellite images (15–30m resolution), a SPOT Pan image (10m resolution) and an ASTER mosaic (15–90m resolution), together with medium altitude aerial orthophotos of the Ministry of Agriculture were used for mapping the archaeological sites of the region. A 20m DEM constructed by stereoscopic SPOT images was also employed for creating maps of elevation, slope and aspect. In this way it was possible to acquire statistical data of the physiographic (topographic and geological) attributes of the archaeological sites. Furthermore, the usage of images of different sensors having variable spectral and spatial resolution contributed to the definition of the spectral signatures of *Soroi* and other distinct archaeological features. Similar work has been carried out in Greece in the past with relative success (Alexakis *et al.* 2008; Barasino and Helly 1985; Sarris 1991; Cooper *et al.* 1991; Brenningmeyer 1997)

The above material was geo-referenced and projected at the same coordinate system (EGSA/

Fig. 1. Examples from various sites identified as Soroi. *Amygdaliou soros to the left and Pantelis soros to the right. Topographic datum columns exist at the top of some of the Soroi, suggesting that they are still used as landmark points.*

HGRS '87). Thematic clusters of the archaeological features were formed depending on their type and chronological phase and they were projected on the various cartographic maps making possible the correlation of different types of archaeological sites with their environmental, topographical, geological and statistical contexts (*Fig. 2*).

3. Spatial analysis

Different thematic maps have been created based on the chronological period of the sites that helped investigate the changing trends of settlement patterns from the Neolithic to the Venetian period. Focusing on the evolution of settlements through the periods of our interest, a number of conclusions can be drawn from the spatial distribution of the settlements (*Fig. 3*). Neolithic settlements are concentrated towards the central west section of the Pediada. Their number drops to less than half during the Early Minoan (EM) period, which represents the lowest number of settlements compared to the rest of the chronological periods. In the beginning of the Middle Minoan Period (MMI-II) we can notice an expansion of the settlements throughout the region with a higher density in the hinterland rather than along the coastal area. The increasing trend of settlements continues during the end of the Middle Minoan period and the beginning of the Late Minoan (MMIII-LMI), when an emphasis is also noticed around the regions of the palatial sites of Knossos and Galatas and the main route that connects them (running along the Karteros

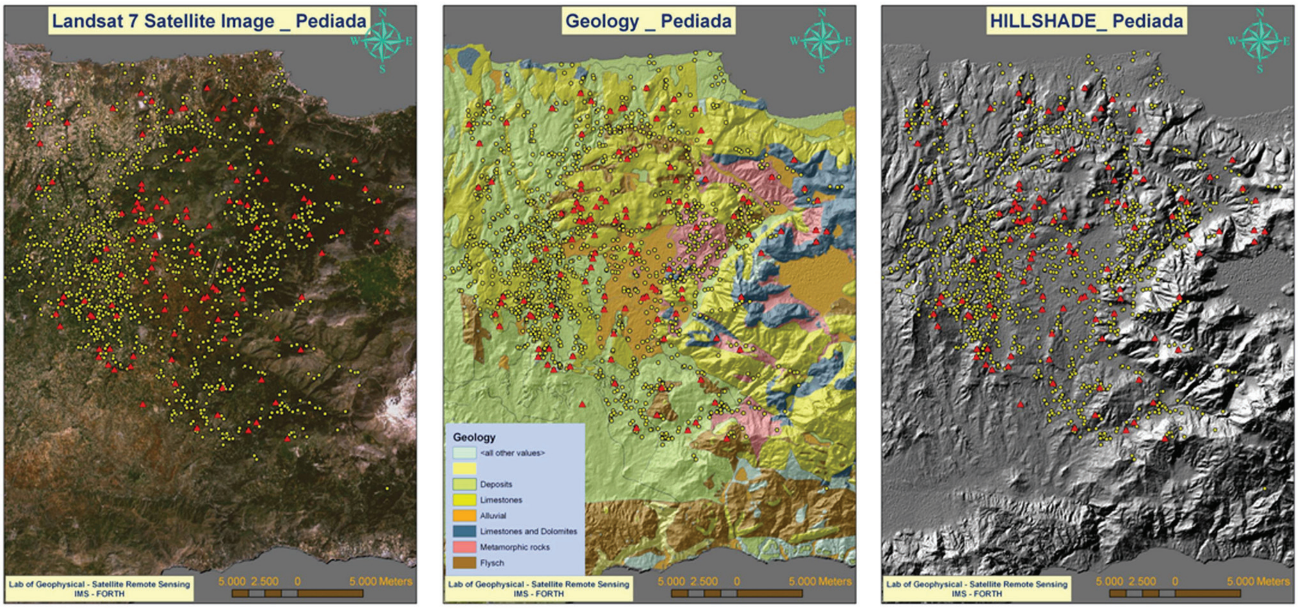

Fig. 2. The archaeological settlements (yellow dots) and Soroi (red triangles) of the Pediada superimposed on the Landsat 7 real color composite (RGB -321) (left), on the generalized geological map (middle) and on the hillshade map of the area (right).

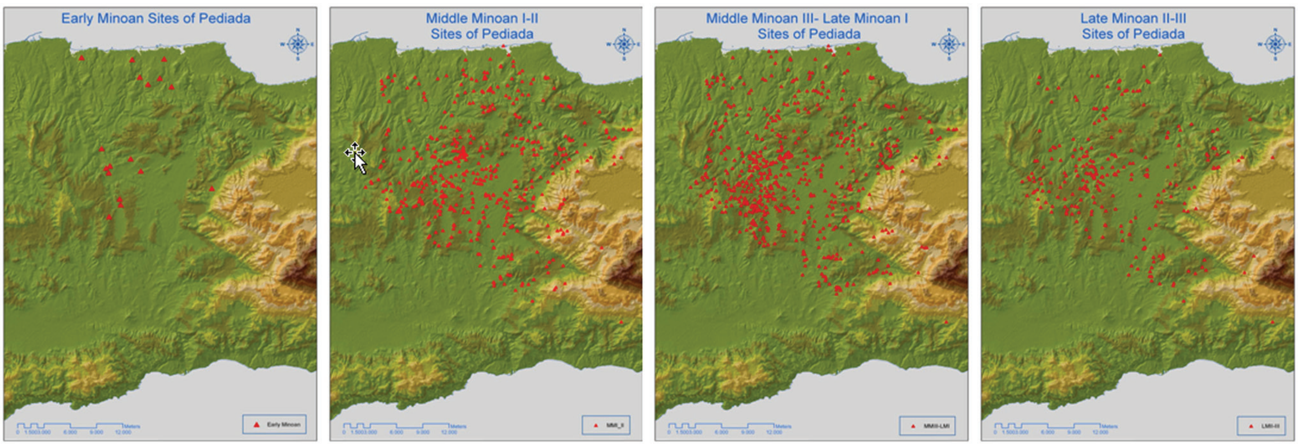

Fig. 3. Evolution of settlement patterns in the area of the Pediada during the different phases of the Minoan Period.

river). The significance of the area of Galatas and the main route along Karteros that the palace must have controlled, remains during the LMII-IIIA and Mycenaean periods, although a decline of the density of the settlements is noticed for the whole region. Finally, as we move towards the Proto-geometric/ Geometric periods the settlement pattern becomes sparse and limited mainly along the Karteros river route indicating the strategic importance of this route and the area around it in all periods (on this importance of this route see, Panagiotakis 2004).

The nearest neighbour index (NNI) was also employed for the study of the clustering degree and the spatial cohesion patterns of the settlements in the various periods. The nearest neighbour index (NNI) is based on the ratio between the observed distance over the expected distance assuming a hypothetical random distribution of sites (Clark and Evans 1954). Values of NNI which are smaller than 1 indicate a clustering of sites, while values of NNI larger than 1 suggest dispersion of sites. According to the results of the analysis which was carried out for settlements of different periods (*Table 1*), almost all chronological periods manifest a clustering of sites. The only deviations are noticed during the Early Minoan and Proto-geometric/Geometric period, where there is a loosening of grouping, in accordance with the archaeological evidence. High clustering is also observed for *Soroi*. These conclusions can be also confirmed by the density maps (radius of 1km) of settlements and *Soroi* (*Fig. 4*). The above results were further tested through comparison of the clustering degree of modern villages which manifest a spatial diffusion in the area of interest.

Considering the settlements of the MMI-II and the MMIII-LMI periods in relation to the *Soroi*, we notice that although there is no clear distinction between the physiographic attributes between the *Soroi* and the settlements, there is a high degree of clustering in each group. This is not a contradiction since the *Soroi* are located in the vicinity of the settlements. Proximity distances have been estimated and it was found that most of the *Soroi* are below 1000m away from the settlements. The rest of them have been located along routes that lead to settlements. The *Soroi* are located either on the top of mountains/hills or within communication routes/passes. Thus, they were mainly used for communication and control management of critical and strategic areas. In the macro-scale range, the location of the *Soroi* guaranteed the inter-visibility among them in order to have a signal propagation from one to the other, independently of

Type & chronology of settlements	NNI	Type of distribution
Early Minoan	1.07	random
MMI-II	0.65	clustered
MMII-III	0.65	clustered
MMIII-LMI	0.63	clustered
PG-G	0.85	Semi-clustered
Orient-Archaic	0.61	clustered
Hellenistic - Classical	0.68	clustered
Roman	0.62	clustered
Byzantine	0.56	clustered
Venetian	0.42	clustered
Soroi	0.01	Highly clustered
Modern villages	1.06	random

Table 1. Statistical analysis of the clustering of archaeological sites in the area of the Pediada.

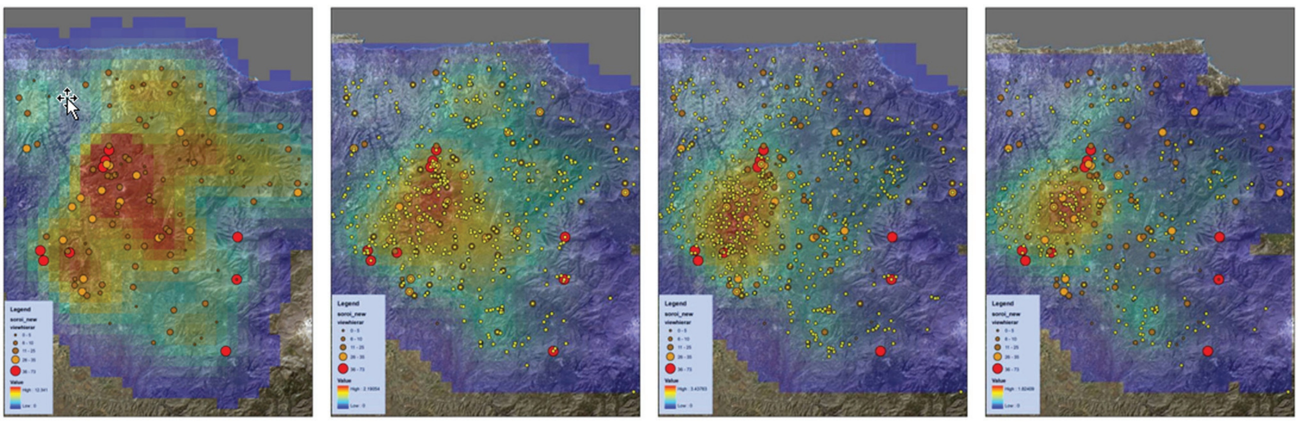

Fig. 4. Density maps (from left to right) for Soroi*, MMI-II, MMIII-LMI and LMII-III settlements. The* Soroi *having the highest inter-visibility are shown with red bullets.*

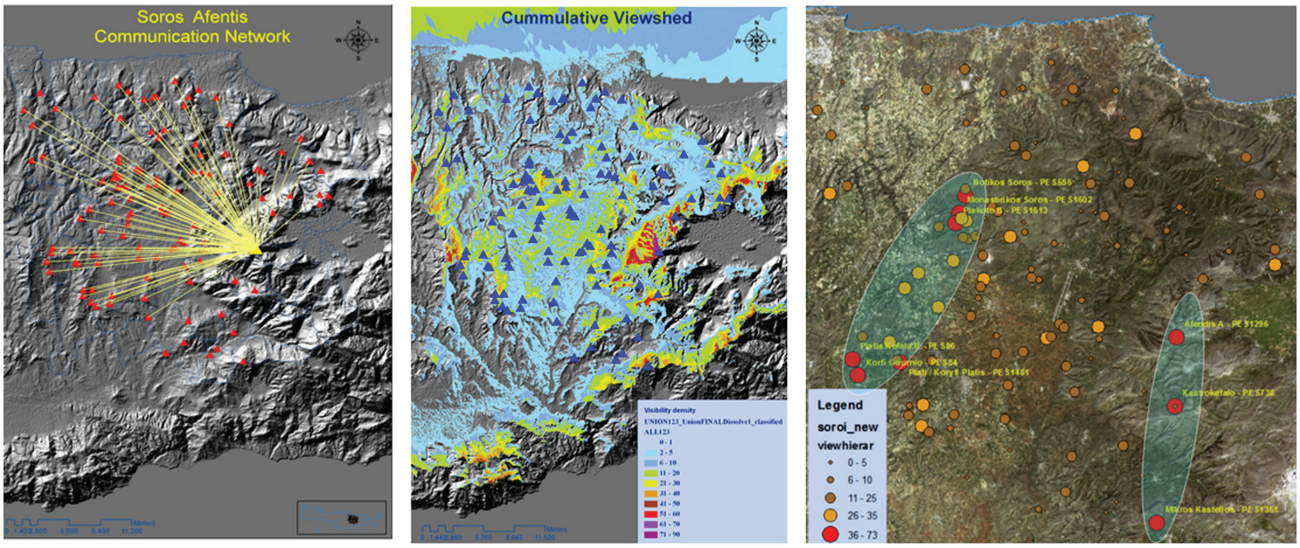

Fig. 5. Results of the line-of-sight analysis for soros of Afendi and communication with the rest of Soroi *in the area of the Pediada (left). Cummulative viewshed analysis suggests that the distribution of soroi is responsible for the coverage of more than 80% of the Pediada region (middle). The hierarchy of soroi in terms of their inter-visibility suggests two groups of significance: one distributed towards the Lasithi mountains (Afentis, Kastrokefalo and Mikros Kastelos) and another distributed towards the west region of the Pediada (Notikos soros, Monastiriakos soros, Plakoto B, Platia Kefala B, Korfi Gournio and Plati/Koryfi Platis). Although, most of them are not located on the highest altitudes of the region, they have the highest inter-visibility that safeguards the Pediada region.*

the elevation of their settings. For example, the inter-visibility of the highest *Soroi* (altitude of 700–1568m) in the Pediada region varies from 1 to 73. The highest inter-visibility is noticed for *Afentis Soros* located at an altitude of 1568m on the Lasithi mountains; it was probably used for communication between east and central Crete (while the important passes from the Lasithi Plateau and east Crete to the Pediada were controlled by the *Tsouli to Mnima Soros* found on the Lasithi mountains but at a lower altitude than *Afentis Soros*). Whatever is the case, viewshed analysis and line-of-sight analysis have proved that there is a dense communication network among *Soroi* and between the *Soro*i and the rest of the settlements of the region (*Fig. 5*).

It is also possible that there has been a hierarchy of them depending on their function, terms of their inter-visibility or extent of control, that can be also related to their dimensions (two categories can be distinguished from fieldwork evidence: the smaller ones covering a total area of less or equal to 1000m^2 and the larger *Soroi* of dimensions about 1500m^2). In an effort to identify the spatial clusters of statistically significant high or low attribute values in viewshed coverage of *Soroi*, the Getis/Ord Gi statistics was applied to the viewshed analysis results. High values for the Getis/Ord Gi statistics indicated the clustering of highly visible areas (Getis and Ord 1992; Ord and Getis 1995). Based on this, it is suggested that the most significant of *Soroi* are located on the mountain ranges that extend to the western and eastern borders of Pediada region (*Fig. 5*).

4. Satellite Remote Sensing and Predictive modelling

SPOT, ASTER and 4 Landsat images (1988, 1994, 1999 and 2003 captures) were processed and enhanced in order to obtain the spectral signatures of the *Soroi* and the rest of the settlements. Initially, all the images were rectified and mosaics were created through the use of DTM and GCPs. Linear and non-linear histogram stretching was applied to all data to achieve a normalized range of reflectivity. Spatial filtering was also carried out to enhance the spatial attributes of the images. Different RGB combinations were applied to enhance the spectral attributes of the region (*Fig. 6*).

The spectral signatures of *Soroi* have been extracted from all satellite sensors and were classified according to the corresponding wavelength band (*Fig. 7*). Basic statistical and multivariable statistical analyses have been carried out for the specific bands. The Pearson's coefficients have been computed for the various bands to show the correlation among them (*Table 2*). SPOT PAN, Landsat bands L1, L4

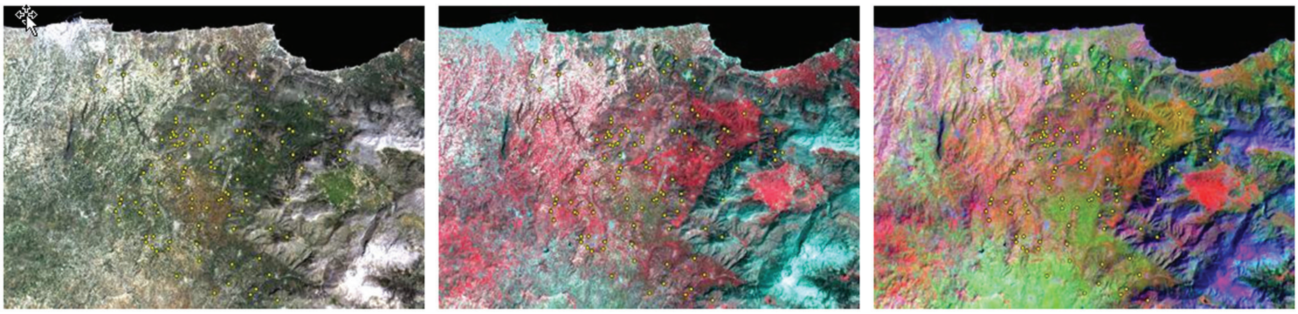

Fig. 6. Various RGB combinations of Landsat-7 image of the Pediada region.
From left to right: RGB->3,2,1, RGB->4,3,2, RGB-> 4,6,1.

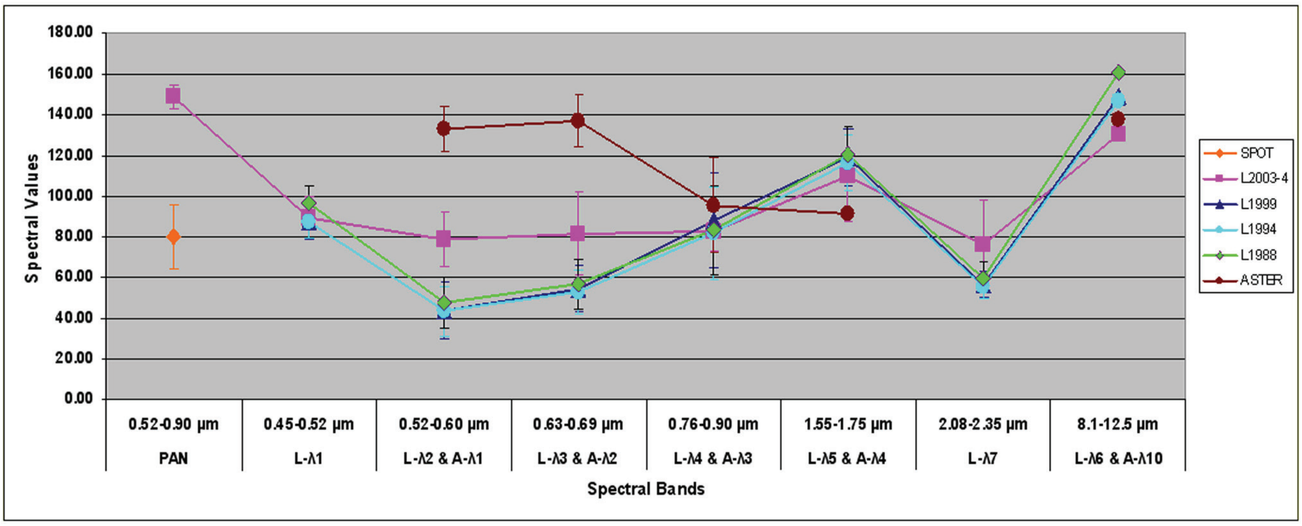

Fig.7. The diagram indicates the spectral signature of the Soroi *for the different satellite sensors. The values of the diagram represent the mean values of reflectivity and the standard deviation.*

		SPOT PAN	Landsat2002_2003								ASTER				
		SPOT PAN	L1band1	L1band2	L1band3	L1band4	L1band5	L1band6	L1band7	L1band8	Aband10	Aband4	Aband3n	Aband2	Aband1
SPOT PAN	SPOT PAN	1	0.77	0.76	0.72	0.20	0.61	0.36	0.61	0.37	0.27	0.74	0.57	0.73	0.68
	L1band1		1	0.97	0.93	0.46	0.81	0.36	0.83	0.37	0.05	0.72	0.56	0.75	0.75
	L1band2			1	0.97	0.53	0.83	0.39	0.85	0.39	0.11	0.75	0.60	0.76	0.75
	L1band3				1	0.44	0.83	0.46	0.87	0.47	0.14	0.73	0.47	0.76	0.74
	L1band4					1	0.47	0.08	0.38	0.08	0.23	0.65	0.58	0.49	0.43
	L1band5						1	0.38	0.97	0.37	0.20	0.77	0.49	0.65	0.62
	L1band6							1	0.41	0.99	0.40	0.32	0.57	0.41	0.39
	L1band7								1	0.41	0.14	0.71	0.47	0.65	0.64
Landsat2002_	L1band8									1	0.40	0.31	0.30	0.41	0.40
	Aband10										1	0.39	0.49	0.26	0.16
	Aband4											1	0.30	0.82	0.70
	Aband3n												1	0.68	0.70
	Aband2													1	0.84
ASTER	Aband1														1

Table 2. Pearson's coefficients for the various bands of the satellite sensors (SPOT, Landsat and ASTER).

and L5 and ASTER bands 3 and 10 showed the least correlation and they were chosen for the subsequent classification analysis. Unsupervised classification using Isodata Clustering has been previously employed without any significant results. Based on the particular statistical analysis, supervised classification was carried out to the appropriate images. Supervised classification uses "training" regions and then finds the rest pixels of the image that have similar spectral characteristics. Eight classes were totally formed representing mainly the surface coverage and land use of the area. The maximum likelihood classifier produced a better classification assessment compared to the mahalanobis distance and minimum distance classifiers.

The land use classification results were imported to ArcGIS 9.2. and only the cultivation or natural vegetation areas were kept. Other thematic layers in the form of binary files were constructed. These layers consisted of 1) areas with elevations within the range of 200–1200m and slope less than 20 degrees, where most of the *Soroi* are located, 2) areas falling within the spectral range of *Soroi*, and 3) areas lying within a buffer zone of 1km away from MMI-II sites. The above layers were combined using Boolean algebra with the same weights of significance resulting a "primitive" predictive model of *Soroi* (*Fig. 8*). Other types of models have been created using different weight factors. The results are encouraging and are still in progress.

5. Conclusions

The results of the above spatial analysis support the hypothesis that *Soroi* may constitute the earliest communication system in the Aegean world, playing a vital role in the Minoan landscape, especially during the MMI-MMIIIA periods. The clustering of the sites, the high degree of inter-visibility among the *Soroi*, the large extent of viewshed coverage by them, their proximity to the settlements, their spatial distribution (either to high elevations relative to the surroundings or close to passes) indicate their role as communication beacons. A probable hierarchy of them is also suggested either by the inter-visibility degree of them or by their location and size. It seems that those located to the western and eastern borders of the Pediada region had an increased strategic significance, as they were controlling the access of the Pediada region from the east and west mountain ranges. Finally, their spectral signature, mainly defined by the traces of burning, together with their

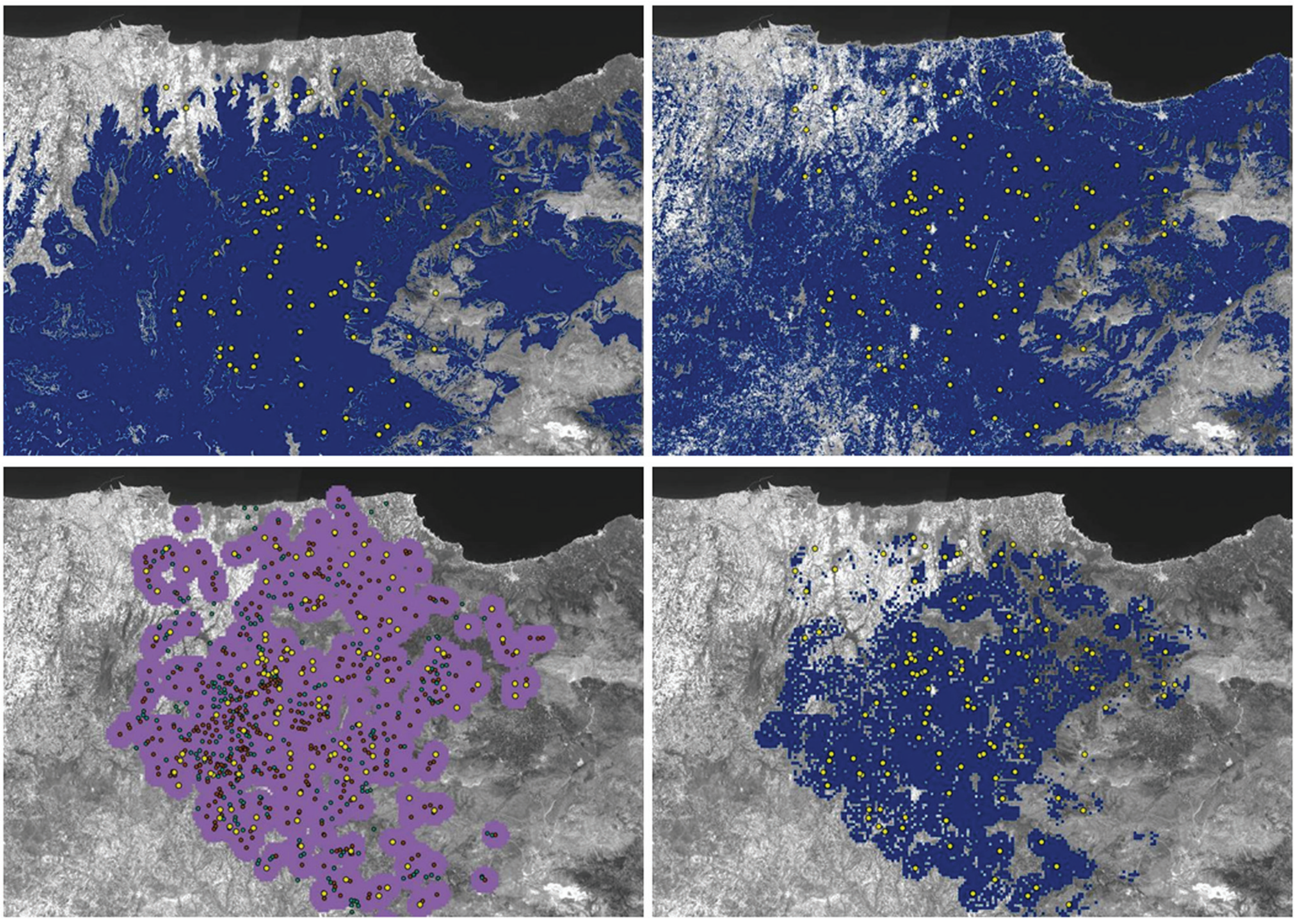

Fig. 8. Areas with altitude 200m<h<1200m and slope<20 degrees (top left). Result of the classification based on vegetation regions (top right). Buffer zones of 1km around MMI-II settlements (bottom left). Final predictive map for the location of Soroi *(bottom right)*

location attributes offer a way of modelling the spatial distribution of them.

Still a number of questions related to the construction of the *Soroi* and their evolution through time needs to be addressed. Some of the *Soroi* may also be identified with Minoan Peak sanctuaries (Panagiotakis 2003, 2004). Is it possible that the most significant of *Soroi*, in terms of their inter-visibility, gained a higher respect as landmarks through time, continuing at the same time to operate as signal beacons? Finally, is this type of structures localized within the borders of Crete or has it a much more global character within the Aegean? In a recent geophysical survey carried out in the hill of "Soros", south of Volos (in Thessaly), traces of burning have been identified by the magnetic prospection techniques. This also supports the significance of the toponyms and the need to expand this kind of research in other geographic regions of the Aegean.

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